Bedrock Channels and Tectonic Geomorphology

River Incision into Bedrock:

- Interaction of a suite of process
  - Plucking, Abrasion (bedrock & suspended load), Cavitation (?),

  Weathering
- Vortices shed off macro-roughness drive processes
  - Relation to mean bed shear stress?
- Critical stress for incision/flood frequency
- Adjustment of channel morphology/bed state
- How non-linear? Relation to Climate?

$$\frac{\partial z}{\partial t} = U - KA^m S^n$$

$$S = (\frac{U}{K})^{1/n} A^{-\frac{m}{n}}$$

$K = f(U,$ Climate$)$, affected by width, roughness, % alluvial bed cover, grain size, etc.

$$k_s = (\frac{U}{K})^{1/n}, \quad k_s = f(U), \quad k_s \propto U^p$$

$Q \neq f(U)$ or $f(K)$

Plucking: $\tau_b > \tau_{crit.}$ block

Beyond $\Rightarrow$ transport capacity of blocks

Bedload Abrasion (saltation) Plane Bed (smooth):

Sklar and Dietrich, 2004, WRR

$$E = V_i I_r F_e$$

$$V_i \propto \frac{{w_{si}}^2}{\varepsilon_v}, \quad I_r \propto \frac{Q_s}{WL_s}, \quad F_e = (1 - \frac{Q_s}{Q_c})$$

where Q_s is sediment flux (supply), Q_c is transport capacity and F_e is fraction exposed bedrock.

$$E = \frac{{w_{si}}^2 Q_s}{2\varepsilon_v W L_s}(1 - \frac{Q_s}{Q_c})$$

$$L_s, Q_s, Q_c = f(\tau_b)$$

$Q_s = \beta A U$ where β is fraction of bedload.

Abrasion by Suspended Load:

$$E_{as} = \frac{S_a q_{ke}}{\rho_r}$$

where ρ_r is rock density, S_a is abrasion susceptibility (ε_v), and q_{ke} is kinetic energy flux.

$$q_{ke} = \frac{1}{2}\rho_r c_v {u_p}^2 \cdot u_p \propto {u_p}^3 \propto {u_w}^3$$

Suspended transport:

$$c_v \propto {u_w}^2, \; q_{ke} \propto {u_w}^5, \; E_a \propto {u_w}^5 \propto {\tau_b}^{5/2}, \; a \cong 5/2$$

We can expect: $1 \le a \le \frac{5}{2}, \; n = \frac{2}{3}a, \; \frac{2}{3} \le n \le \frac{5}{3}, \; \tau_b > \tau_c$

Critical Shear Stress and Flood Frequency Distribution:

Tucker and Bras, 2000, WRR (see more in stochastic_storms_bedrock_chns.ppt)

Snyder et al, 2003, JGR

Tucker, 2004, ESPL

$$K = K' K_{\tau c}$$

$$E = K_{eff} A^m S^{n=1}$$

$$k_s = U^{1/n} K^{-1/n}$$

Response Time:

The profile reaches steady state when the lower segment reaches $x = x_c$, or when:

$$z(x_c) = z_f(x_c)$$

Time to steady state is given by the ratio change in elevation at $x = x_c$ to the rate of change of elevation at $x = x_c$:

$$T_U = \frac{\text{distance}}{\text{velocity}} = \frac{z(x_c)_f - z(x_c)_i}{U_f - U_i}$$

$$U_f - U_i = U_i(f_U - 1) \text{ where } f_U = U_f / U_i$$

$$z(x_c)_i = \beta K_i^{-\frac{1}{n}} U_i^{\frac{1}{n}} + z(L)$$

where $\beta = k_a^{-m/n}(1 - \frac{hm}{n})^{-1}[L^{1-\frac{hm}{n}} - x_c^{1-\frac{hm}{n}}]$; $x_c \neq f(U)$; L ? x_c

$$z(x_c)_f = \beta K_f^{-\frac{1}{n}} U_f^{\frac{1}{n}} + z(L)$$

For a change in U only, $K_i = K_f = K$

$$z(x_c)_f - z(x_c)_i = \beta K^{-\frac{1}{n}}(U_f^{\frac{1}{n}} - U_i^{\frac{1}{n}}) = \beta K^{-\frac{1}{n}} U_i^{\frac{1}{n}}(f_U^{\frac{1}{n}} - 1)$$

$$T_U = \frac{\beta K^{-\frac{1}{n}} U_i^{\frac{1}{n}}(f_U^{\frac{1}{n}} - 1)}{f_U - 1}$$

$$\frac{dz}{dt} = -\frac{K_f U}{K_i} + U = U(1 - f_K) \text{ where } f_K = K_f / K_i$$

$$T_K = \frac{\beta K_i^{-\frac{1}{n}} U^{\frac{1}{n}-1}(f_K^{\frac{1}{n}} - 1)}{f_K - 1}$$

Assumptions:

- $x_c \neq f(U, K)$; L ? $x_c \Rightarrow \beta = \text{constant}$
- Slope is unchanged above knickpoint

  Retain sharp knickpoint $\Rightarrow$ no information is passed upstream

  T_U : 1Ma

Transport-Limited Incising Channels (Alluvial but Erosional):

$$\frac{\partial z}{\partial t} = U - \frac{1}{1 - \lambda_p}\frac{\partial q_s}{\partial x}$$

$$Q_c = W q_s = K_f A^{m_f} S^{n_f}$$

For gravel bedload, $m_f = 1,\ n_f = 1$

For send total load, $m_f = 1.5,\ n_f = 2$

Details: channel closure downstream fining

$$\tau_b = (1+\varepsilon)\tau_c \ \text{ or } \ W = k_w Q^b$$

Bedload: $q_s \propto {\tau_b}^{3/2}$, $n_f = \frac{2}{3} \times \frac{3}{2}$

Rapid downstream fining: m_f : 1.5

Steady State Profile?

$$Q_c = Q_s$$

$$K_f A^{m_f} S^{n_f} = \beta_g A U$$

$$S = \left(\frac{\beta_g U}{K_f}\right)^{\frac{1}{n_f}} A \frac{1-m_f}{n_f}$$

$$m_f = 2,\ n_f = 2 \Rightarrow \theta : \frac{1}{2}$$

Hillslopes, suspended sediments: $q_s \propto {\tau_b}^3$

Under what conditions are channels detachment-limited (DL) vs. transport limited (TL)?

Definition: DL: Q_c ? Q_s , TL: $Q_c \le Q_s$

$$N_{br} = \frac{Q_s}{Q_c}$$

$$N_{br} < 1 \Rightarrow \text{DL (mixed)}, \quad N_{br} \ge 1 \Rightarrow \text{TL}$$

Steady state:

$$Q_s = \beta_g A U,\ Q_c = K_f A^{m_f} S^{n_f}$$

Assume channel is DL, $S = \left(\frac{U}{K}\right)^{\frac{1}{n}} A^{-\frac{m}{n}}$

$$Q_c = K_f A^{m_f} \left[\left(\frac{U}{K}\right)^{\frac{1}{n}} A^{-\frac{m}{n}}\right]^{n_f}$$

Mountain channels $\Rightarrow$ gravel bedload $\Rightarrow n_f = 1$

$$N_{br} = \frac{Q_s}{Q_c} = \frac{\beta_g}{K_f} K^{\frac{n_f}{n}} U^{1-\frac{n_f}{n}} A^{1-m_f+\frac{mn_f}{n}}$$

1. If K goes up (wetter/stormier; weaker rock) or K_f goes down or β_g goes up $\Rightarrow$ TL
2. If and only if $n < n_f$, U goes up $\Rightarrow$ DL